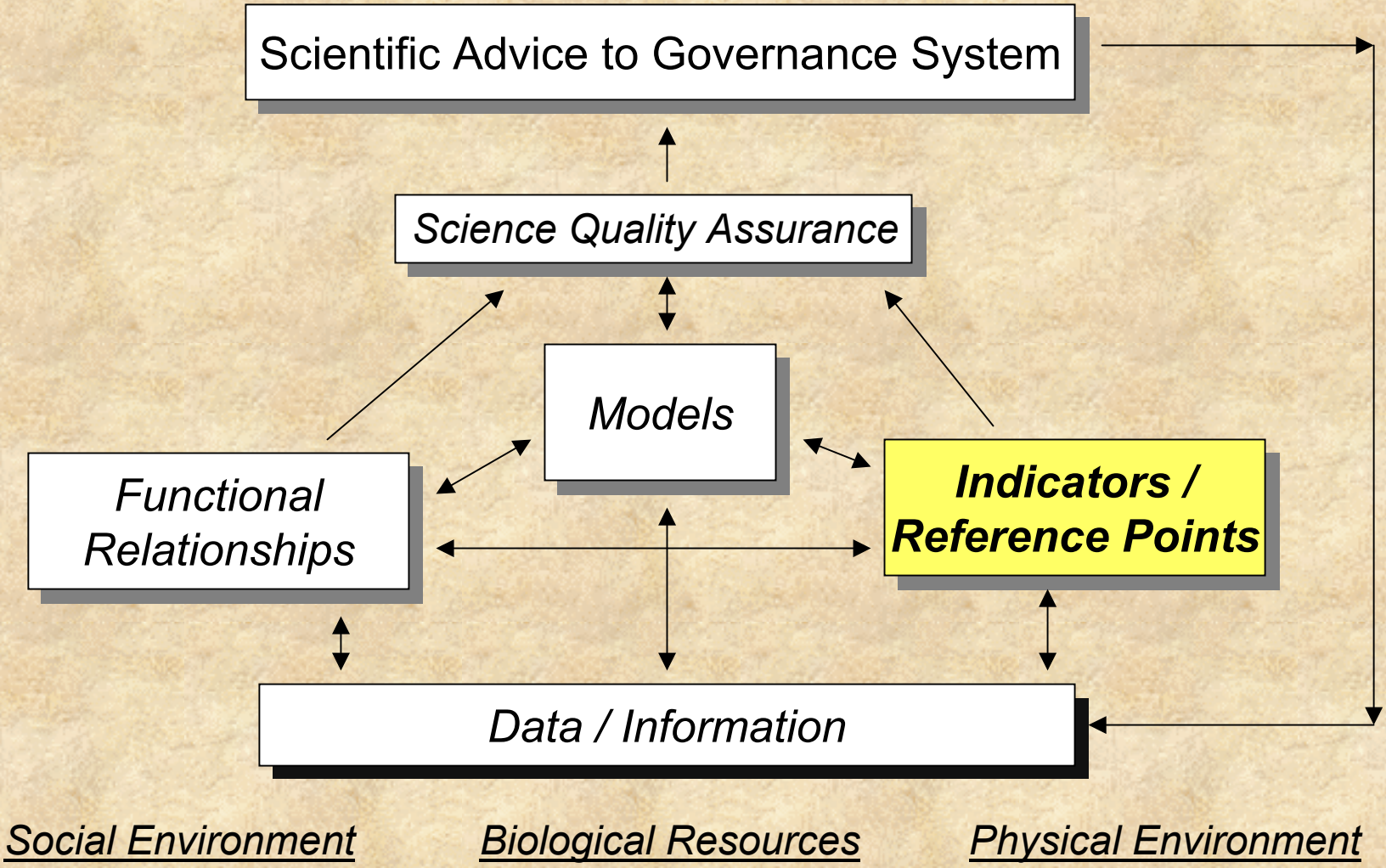
Ecosystem Indicators*

Marie-Joelle Rochet
Kerim Aydin/Pat Livingston
Jason Link

*A hodgepodge of ideas merged together from a bunch of different talks that we've given in the past few years

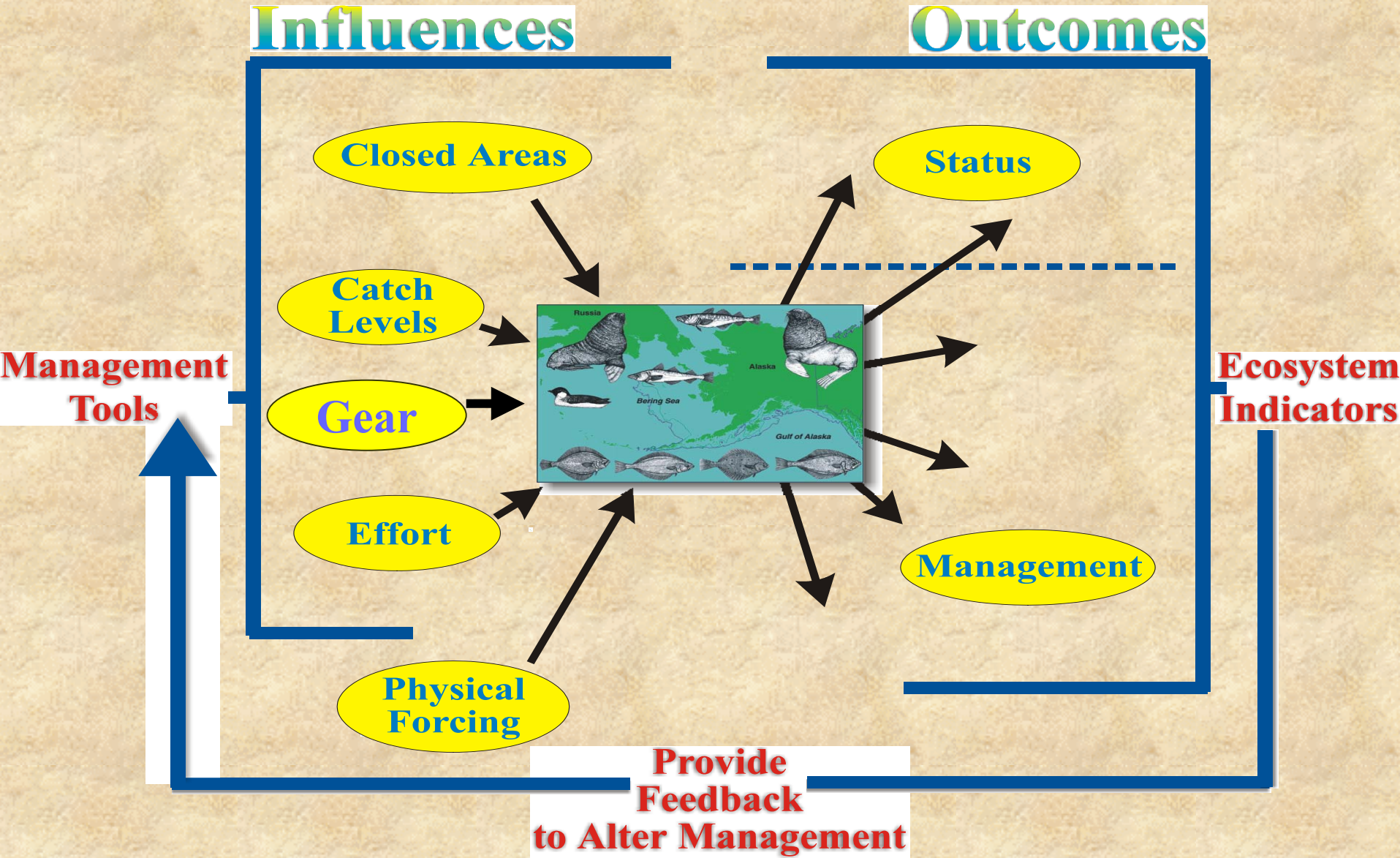
Quantitative Decision Tools Supporting Ecosystem Approaches to Fisheries



Ecological Considerations in Fisheries & Protected Resources Management

- Accompanies single species stock assessment advice
- Provides status and historical trend information of ecosystem components using scientific information from a variety of experts and agencies
- Contains species, community, and ecosystem-level indicators and indicators of environmental and human impacts
- Track efficacy of ecosystem-based management efforts
- Meets the national fishery management scientific information requirement (National Standard 2) to include information on past, present, and possible future condition of the stocks, marine ecosystems, and fisheries being managed in the stock assessment and fishery evaluation reports provided to managers.

Ecosystem Measures and Influences



Pillars of Any Management System

1. Goal Setting (Where do we want to be; i.e. allocation)

2. Assessing System Status (Where are we relative to where we want to be; i.e. assessment & prediction)

Indicators are used at all steps in the process

3. Achieving Ecosystem Goals (How do we move to where we want to be; i.e. management)

What is an Indicator?

Audience participation here!!!

That would be you.

OK, any time now….

Indicators Operate at Multiple Levels

- Ecological issues considered in managing individual species
  i.e. the stock level (Tier III)

- Ecosystem structure, function and productivity
  resulting from cumulative impacts of human activities
  i.e. the system level

- **Both are needed for EAF**

Different kinds of EAF Indicators

Statistical models

Mechanistic models

Both are valid

Both are empirical

Ecosystem Indicators: Two Particular Roles for EAF

STATUS

- **Link ecosystem research to traditional fisheries advice**
- **Provide new understanding of ecosystem connections**

MANAGEMENT

- **Provide early warning of human effects**
- **Track efficacy of previous management efforts**

Ecosystem Indicators: Status

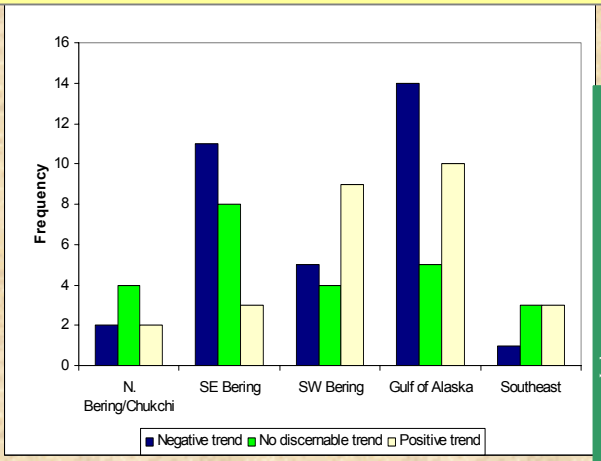
- Assess historical ecosystem trends and influences
  -TS, PS, NTS, & Systemic indicators
  -what is the recent history?

- Determine status of present ecosystem state
  -where are we relative to where we want to be ?

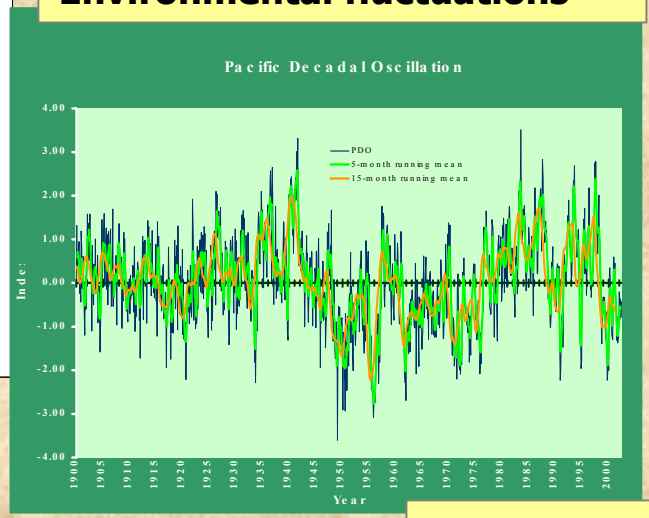
- Provide forecasts for future ecosystem attributes
  -in short-, medium- and long-term
  -what are the effects of trends/variations in abiotic factors?
  -what are the effects on other biota
  -what are the effects of alternative policy choices?
  (also called management scenario analysis)

ECOSYSTEM STATUS INDICATORS

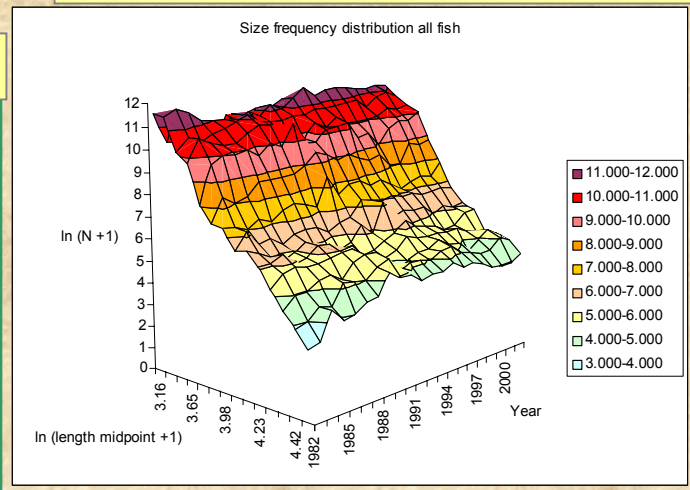
Seabird population trends



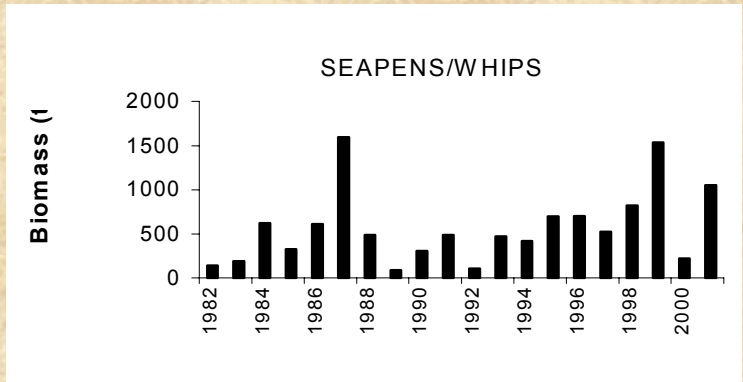
Environmental fluctuations



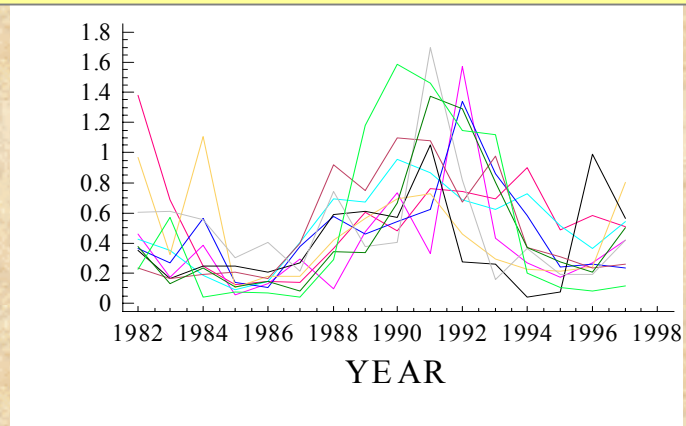
Fish community size spectrum



Status of structural habitat biota



Population trends of non-target fish species



Ecosystem Indicators: Management

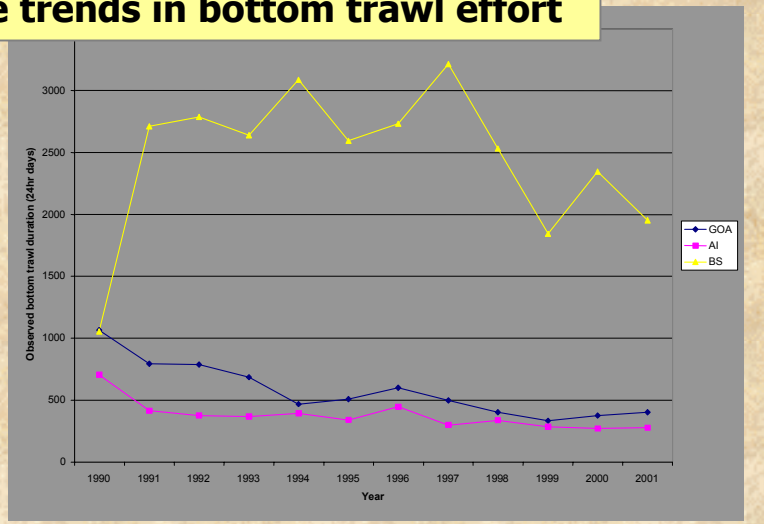
- Set thresholds and limits
  -what do we know is precautionary?
  -if not able to pick what ecosystem state is desirable,
  at least what states do we want to avoid?

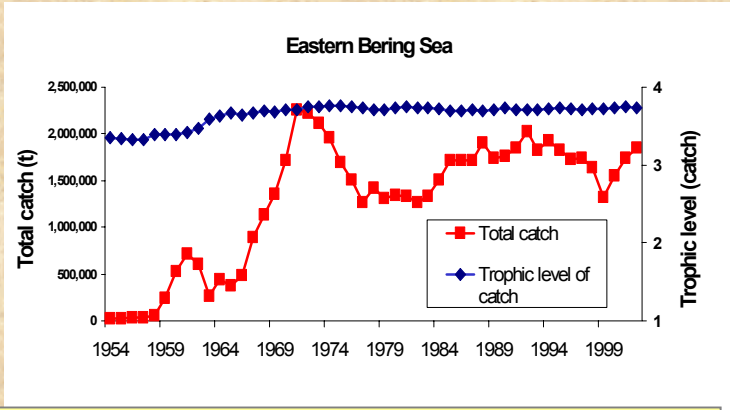
- Evaluate performance of past management actions
  -where are we relative to where we want to be ?
  -what did we do to get here?

- Invoke control rules
  -what actions need to be taken to achieve objectives?
  -what are the effects of alternative policy choices?
  (also called management scenario analysis)

MANAGEMENT INDICATORS

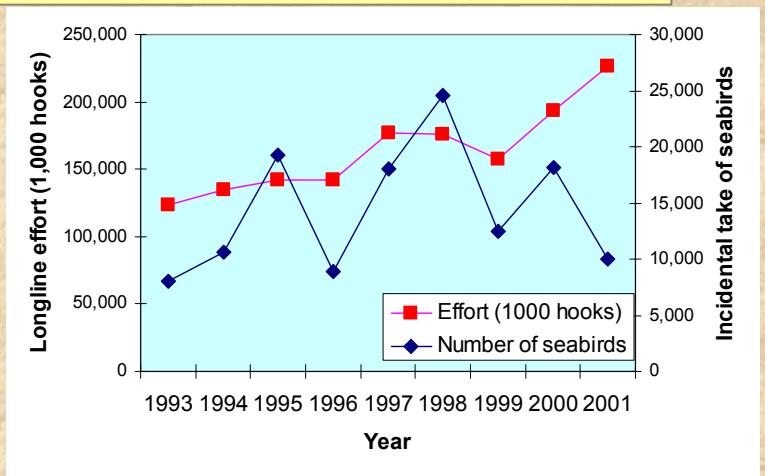
Time trends in bottom trawl effort

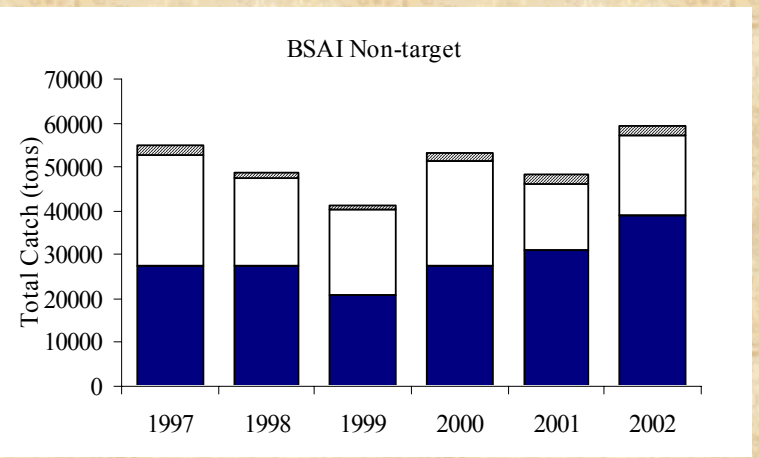




Total catch and trophic level of catch

Seabird bycatch and fishing effort





Amount and composition of non-target fish species in catch

20 Indicators from WG 119

- 3 Physical & Biological Oceanography

  PDO, ENSO or SOI, CPR derived plankton indicators

- 7 Fish and Invertebrate Species

  Species distribution / relative abundance, Size distribution of species, Exploitation rate, Ratio of target to non-target species, Ratio of endangered species to non-endangered species, Traditional measures of species richness and diversity, Genetic diversity

- 5 Size-based

  Average length of fish, Condition indices of fishes, Mean length at maturity of fish assemblage, Proportion of large species in assemblage, Slope and height of the fish size spectrum

- 5 Trophodynamic

  FIB, Catch ratios, Productivity and consumption ratios, System mean transfer efficiency, Primary production required to support catches

Abiotic	*Metric*	*Units*	*Time period*
Oceanic and atmospheric conditions	Sea level anomaly	Centimeters	1970 – 2001
	Shelf-slope front	Kilometers	1975 – 2001
	Gulf stream position	Kilometers	1979 – 2001
	Volume of source (%CIL)	%	1970 – 2002
	RIVSUM	Cubic meters per second	1914 – 2002
	SST anomaly (satellite)	^{o} C	1981 – 2002
	Bottom area < 3^{o} C	Square kilometers	1970 – 2002
	SST at Halifax	^{o} C	1926 – 2001
	100m T, Misaine Bank	^{o} C	1947 – 2002
	250m T, Emerald Basin	^{o} C	1950 – 2002
	Ice (area x duration)	10^4 Km^2 x day	1962 – 2002
	Nitrate	Micro-molar	1976 – 2002 (n=13)
	Oxygen	Micro-molar	1936 – 2002 (n=15)
	Stratification, 0-50m	Sigma-t units	1950 – 2001
	Mixed layer, sigma-t	Sigma-t units	1915 – 2002
	Mixed layer, salinity	Parts per thousand	1915 – 2002
	Mixed layer, temperature	^{o} C	1915 – 2002
	Mixed layer depth	Meters	1915 – 2002
	Storms	Number per year	1895 – 2002
	Wind stress amplitude (two)	Pascals	1953 – 2001
	Wind stress, alongshore	Pascals	1953 – 2001
	Wind stress, cross-shore	Pascals	1953 – 2001
	NAO	Millibars	1895 – 2002

Human	***Metric***	***Units***	***Time period***
Fishing activities	**Landings, groundfish**	**Metric tons**	**1960 – 2002**
	Landings, pelagics	**Metric tons**	**1960 – 2002**
	Landings, invertebrates	**Metric tons**	**1960 – 2002**
	Relative F	**%**	**1970 – 2002**
	Area trawled (vessels >150 GRT)	**Km^2**	**1970 – 2002**
	Landed value, groundfish	**CDN $**	**1976 – 2000**
	Landed value, pelagics	**CDN $**	**1976 – 2000**
	Landed value, invertebrates	**CDN $**	**1976 – 2000**
Drilling and contaminants	**PCB in seals**	**Mg/kg of lipid**	**1976 – 1994 (n=8)**
	Seismic testing: 2D	**Kilometers**	**1960 – 2002**
	Seismic testing: 3D	**Kilometers**	**1985 – 2002**
	Oil and gas wells	**Number per year**	**1967 – 2002**

Biotic	*Metric*	*Units*	*Time period*
Biological abundance	**CPR: Para/Pseudocalanus**	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	Calanus hyperboreus	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	Calanus finmarchicus	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	Diatoms	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	Dinoflagellates	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	Colour	**Counts per tow**	**1962 – 1973; 1991 – 2001**
	RV: Pelagic abundance	**Numbers of fish**	**1970 – 2002**
	Pelagic biomass	**Kilograms**	**1970 – 2002**
	Groundfish abundance	**Numbers of fish**	**1970 – 2002**
	Groundfish biomass	**Kilograms**	**1970 – 2002**
	Grey seal pups	**Numbers**	**1962 – 1997**
	Grey seal adults	**Numbers**	**1968 – 2002**

Biotic	*Metric*	*Units*	*Time period*
Higher level indicators	Pelagic:demersal (biomass)	Non-dimensional	1970 – 2002
	Pelagic:demersal (abundance)	Non-dimensional	1970 – 2002
	Diversity, Margalef's d	Non-dimensional	1970 – 2002
	Diversity, Shannon	Non-dimensional	1970 – 2002
	Divesity, Bray-Curtis	Non-dimensional	1970 – 2002
	Individual weight per fish	Kilograms	1970 – 2002
	Community condition – K	Grams	1970 – 2002
	Community condition – J	Grams	1970 – 2002
	Community condition – area	Km^2	1970 – 2002
	Length at age 6, haddock	Centimeters	1948 – 1959; 1970 – 2002
	Length at age 6, cod	Centimeters	1970 – 2002
	Length at age 6, Pollock	Centimeters	1970 – 2002
	Length at age 6, silver hake	Centimeters	1970 – 2002
	Diatom:dinoflagellate ratio	Non-dimensional	1962 – 1973; 1991 – 2001

Environment (Physio-chemical)	Bottom/surface temperature, Bottom/surface salinity, delta Sigma-T, difference between Bott & Surf Temp, Water Volume from Scotian Shelf, Current velocities, etc.
Habitat (Benthos)	Percent of bottom that is gravel, sand, mud; distribution of hangs/snags; distribution of bolders, bedrock and/or other high rugosity sites; distribution of corals and unique other biotic habitat multi-beam sonar maps, etc.
Contaminants	Concentration of organic hydrocarbons, concentration of (polyvalent) metals, concentration of Nitrogen, P, S, concentrations of the above in tissues of key spp., etc.
Diversity (i.e., biomass allocation)	Percentage of fish biomass in various aggregate groupings, guilds, trophic levels; size spectra; community diversity indices (e.g., richness, evenness, etc.), etc.
Productivity (& cybernetics)	chl *a*, phytoplantkon community composition, zooplankton biomass and community composition; growth rates, mortality rates, production rates of key species, total system production (by TL), total system biomass, ascendancy, redundancy, etc.
Trophodynamics	Number of Species interactions, diet composition of major species, mean TL, % Omnivory, % Cannibalism, Connectivity, Linkage Density, Cycling, etc.
Canary Populations	Incidence of disease/parasites, biomass/abundance of non-economic but ecologically valuable spp., etc.
Human	Total number of vessels, DAS, Total Landings by species, Total Income, Income per vessel, Landings by port, Bycatch rates, etc.
Pulse perturbations (e.g. hurricanes, invasive spp., etc.)	???? Likely same as above

Ecological Indicators from NEFSC Eco. Status Report

- Human, Abiotic, Biotic Metrics
- Multiple ranges of biology, from plankton to whales
- >200 Indicators examined

- And so on, with numerous examples from many other ecosystems
- Indicator Vetting (culling?) Exercises and Protocols Needed

Deciding How Many Indicators Are Needed

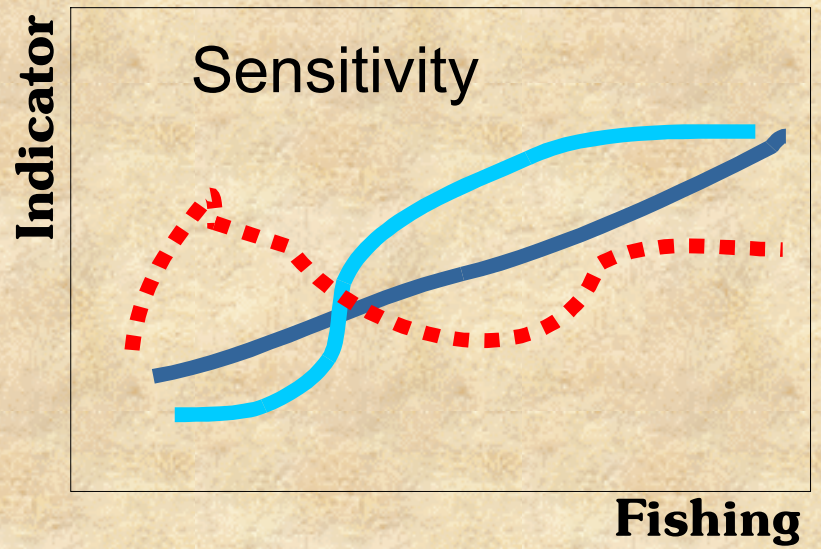
Goal – Minimum number of Indicators to cover ecosystem, social & economic objectives.

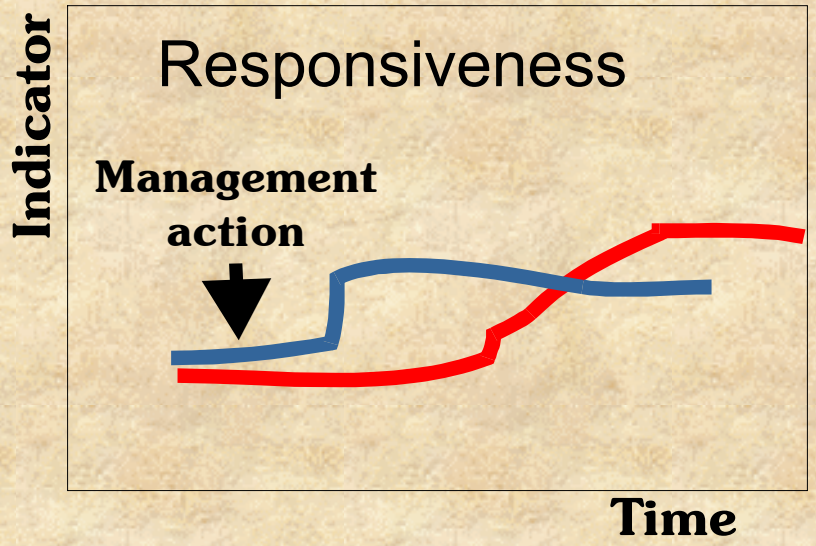
Constraints- data & models

Non constraints- laundry list of candidate indicators

Conundrum- which ones do we need and which ones can we calculate?

Differences in Sensitivity/ Responsiveness





Good **Intermediate** **Poor**

Vetting Indicators

Desirable Properties of Indicators:

- Directional
- Sensitive to change
- Range spans natural variability
- Precision and variance estimable & reasonable
- Unambiguous
- Not duplicative nor repititious
- Expressive/representative of key processes

Indicators alone DNE Reference Points

Using Indicators for EAF

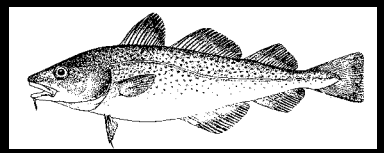
- Stock assessment
  - Estimation B, F
  - Reference points B_{lim}, F_{pa}
  - Stock status: safe / unsafe
- Projections
  - Scenario 1: trends in B & F
  - Scenario 2: trends in B & F
  - ...
- Advice: the best action to take

Population model

- Ecosystem assessment
  - Indicators estimations
  - Reference points?
  - Ecosystem status: multidimensional
- Projections
  - Scenario 1: trends in indicators
  - Scenario 2: trends in indicators
  - ...
- Advice: multidimensional consequences of actions

Gradient of Possibilities

Stock/Single Species

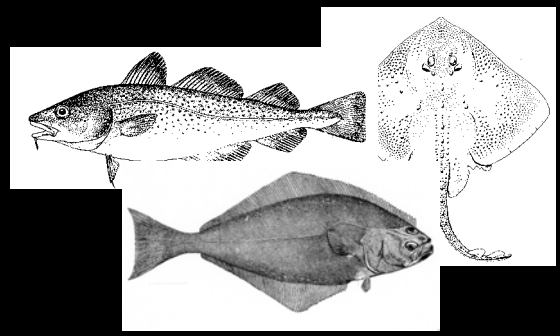


SS models, forget ecosystem issues

SS assessments with explicit M2 or habitat or climate considerations

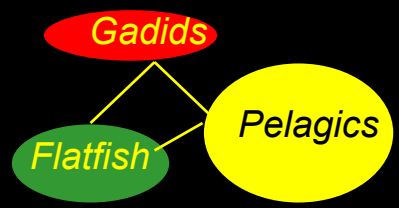
Multiple SS assessments in “harmony”

Multi-species



Multi-species assessments

Aggregate Biomass

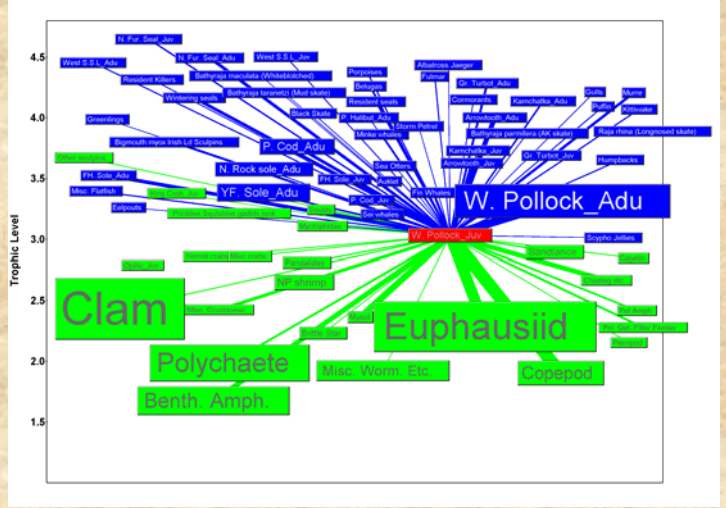


Aggregate Biomass Models

Ecosystem

Messy Picture Here

Whole System Models, forget pop dy



Results for use in stock assessments + "Ecosystem" assessment: NEPA requirement

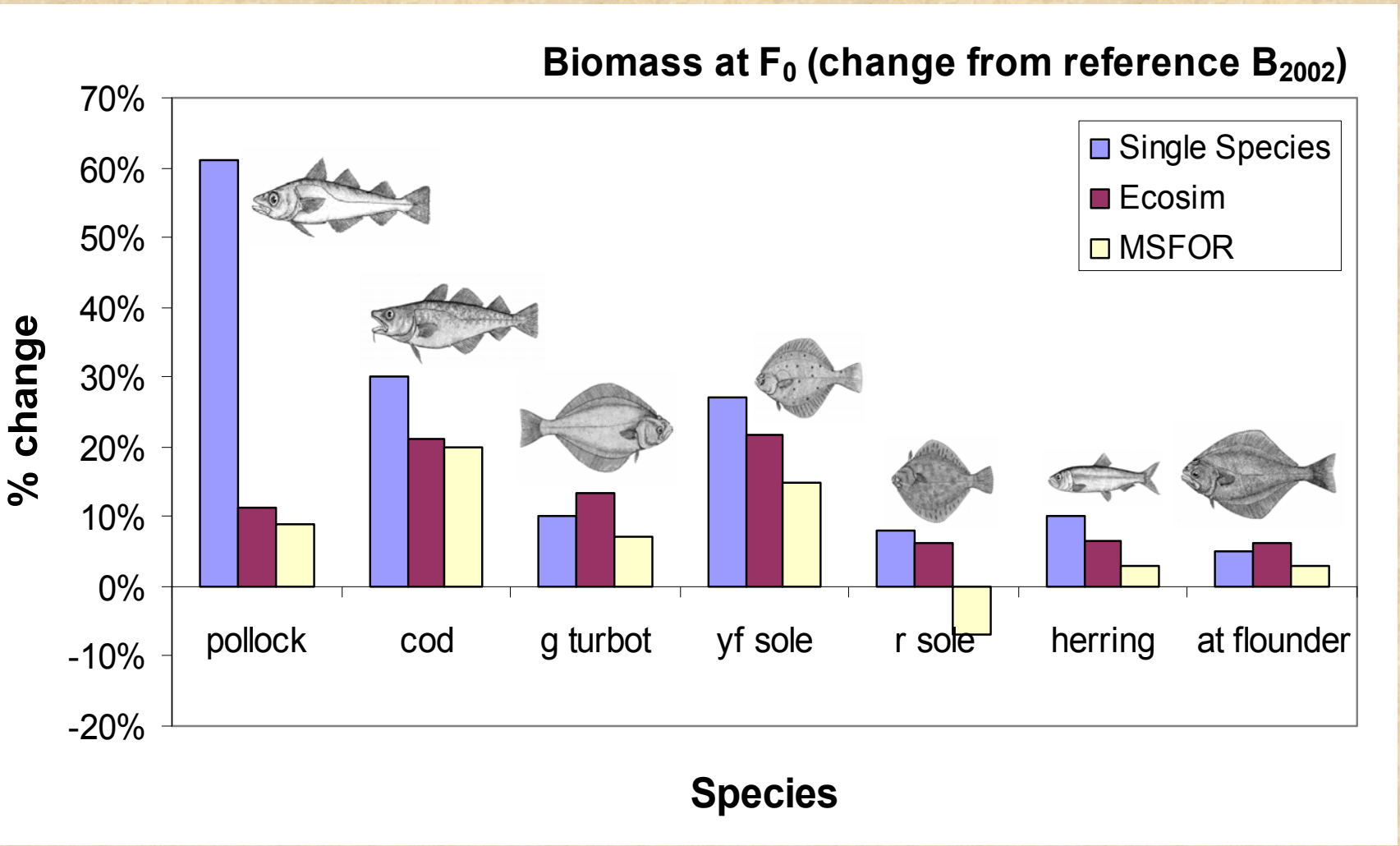
Table 15.15. Ecosystem effects

Ecosystem effects on Atka mackerel			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys	None	Unknown
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Possibly lower mortality on Atka mackerel	No concern
Birds	Stable, some increasing some decreasing	Affects young-of-year mortality	Unknown
Fish (Pacific cod, arrowtooth flounder)	Pacific cod and arrowtooth abundance trends are stable	None	No concern
Changes in habitat quality			
Temperature regime	2002 AI summer bottom temperature 2nd coldest year after 2000 survey	Colder than average year, could possibly affect fish distribution	Unknown

Translation of Ecosystem Indicators into Decision Criteria

Reference points (surfaces, regions, directions, etc.), Control rules, decision theoretics, etc.

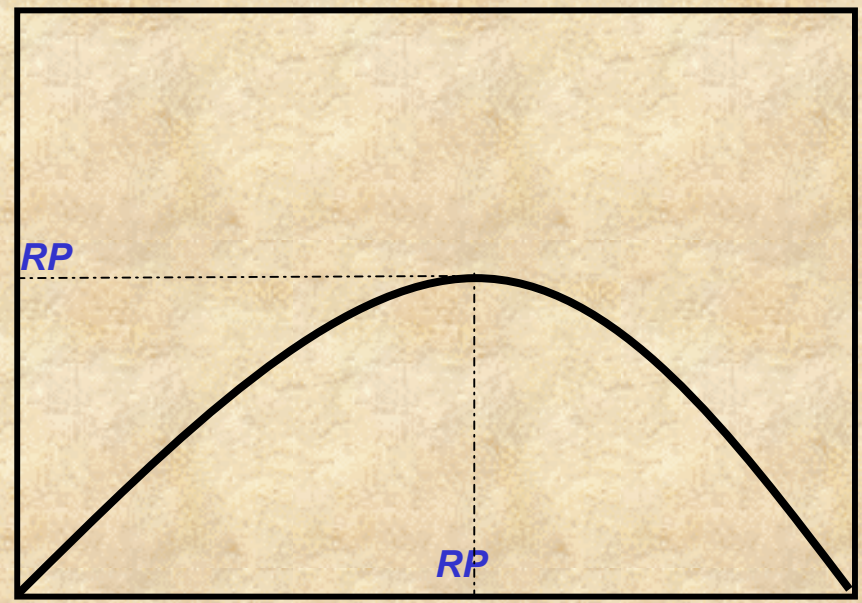
Why multispecies? What reference points?



Reference Points

Single Species Fisheries-

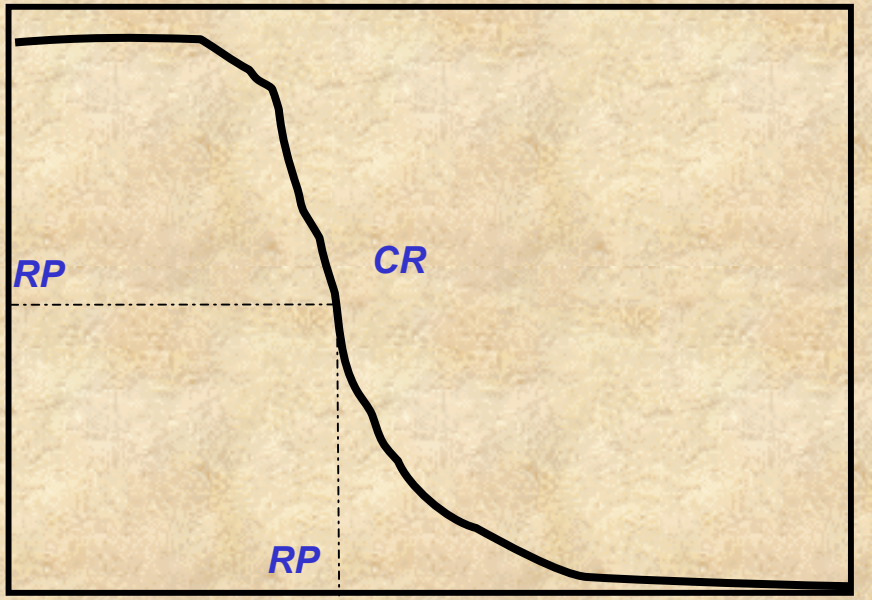
- **Model & empirical-based ref points**
- **Model-based control rules- Arbitrary?**
- **Action to be taken shows direction and magnitude**



Reference Points

Toxicity & Ecological Risk Assessment-

- **Model & empirical-based ref points**
- **Model-based control rules- Arbitrary?**
- **Action to be taken shows direction and magnitude**



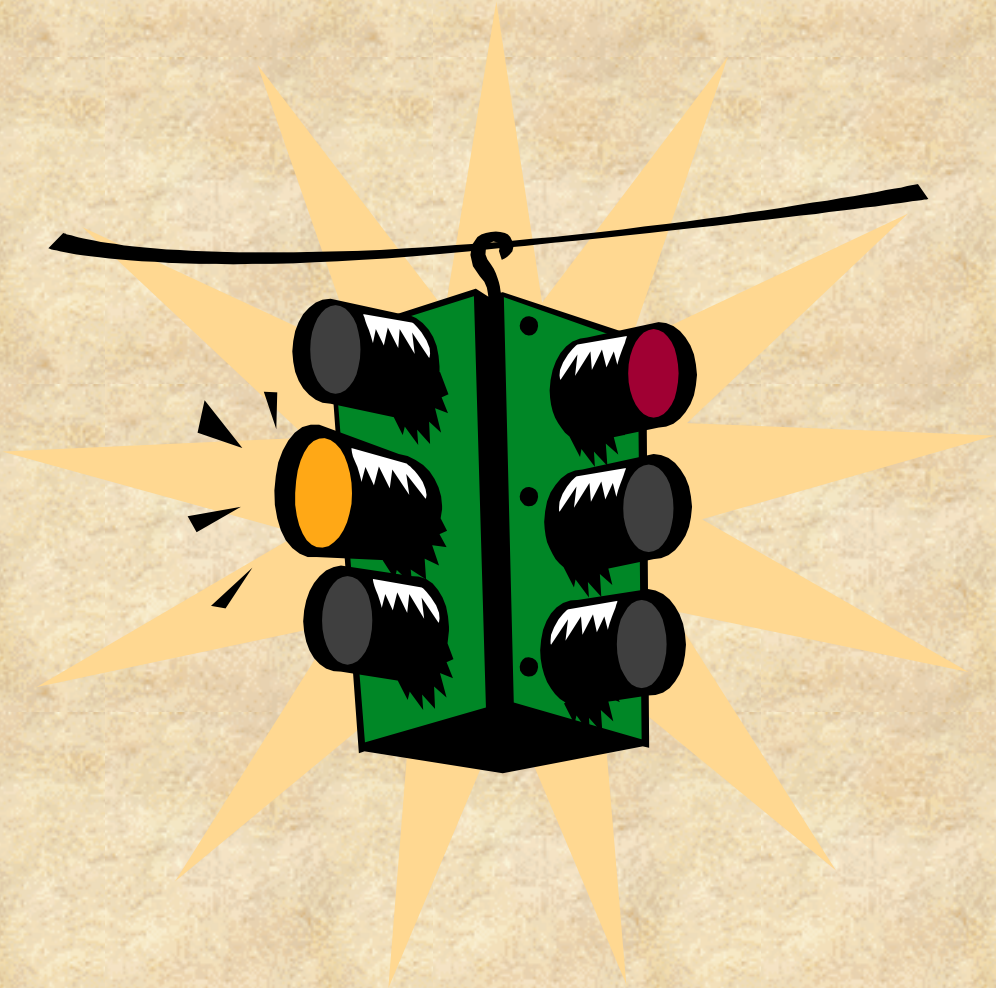
Traffic light/consumer report approaches

Metric 1

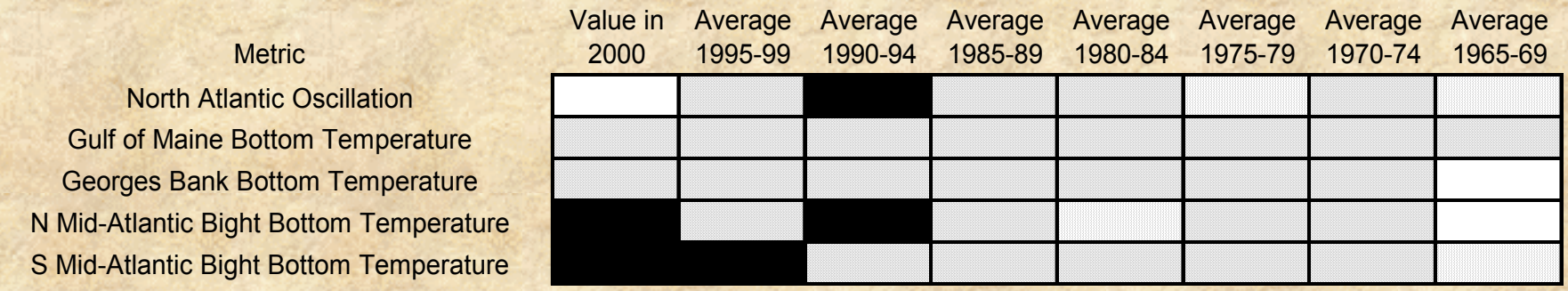
Metric 2

Metric 3

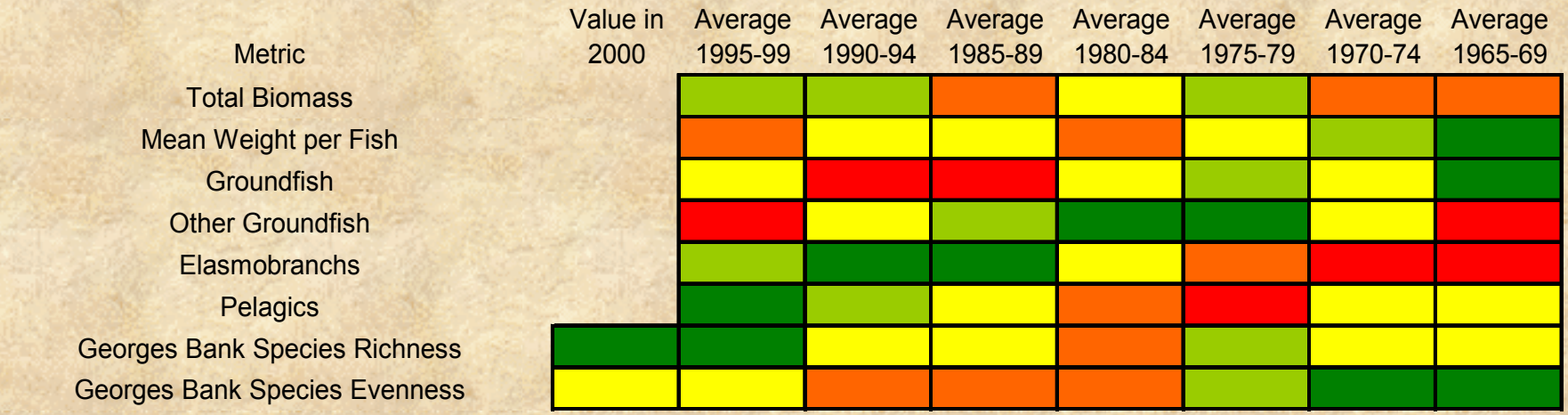
Etc.



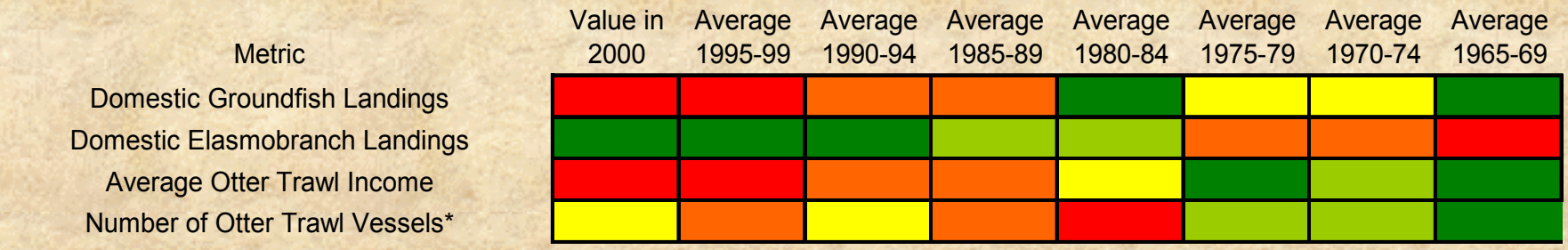
Abiotic metrics



Biotic metrics



Human metrics



*Order of quintiles is reversed

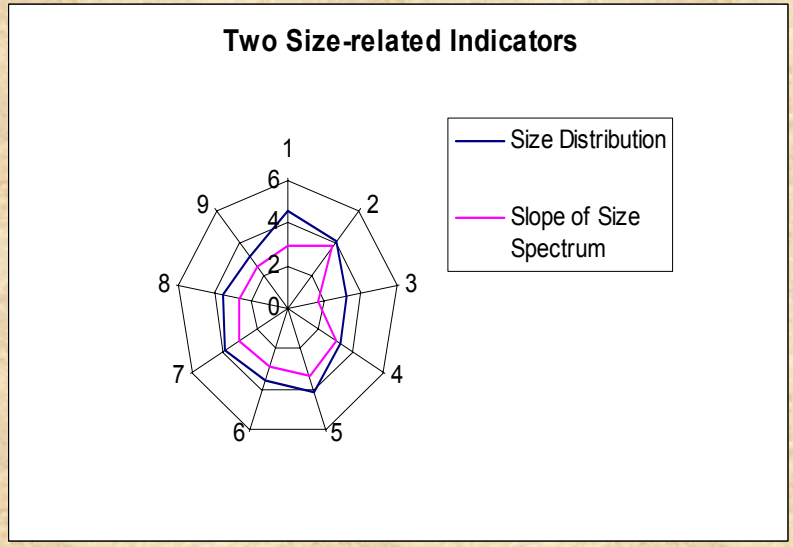
Indicator-Based Reference Points & Thresholds- Empirically Derived

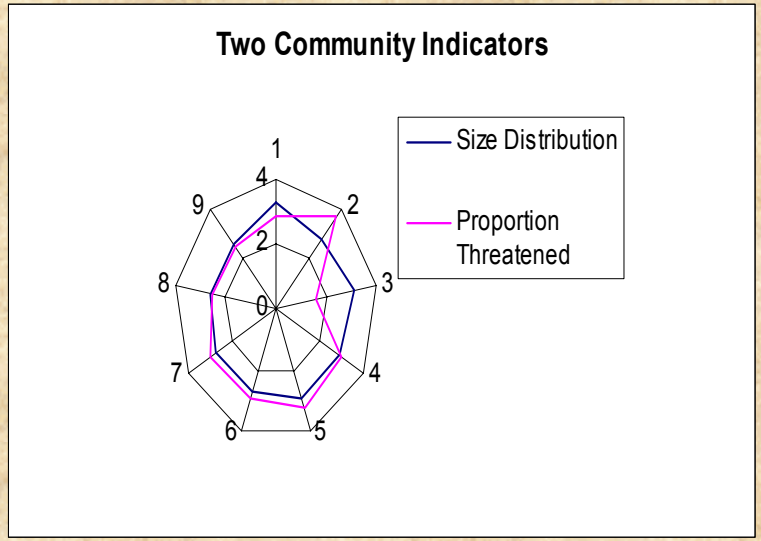
Indicator	Description	Warning Threshold	Limit Reference Point
l	Mean length, all spec.	30%	50%
β	Slope size spectrum, all spec.	N/A	10%
$B_{flatfish}$	B of all flatfish spec.	$B_{flatfish}$ >50% B_{Σ}	$B_{flatfish}$ >75% B_{Σ}
$B_{pelagic}$	B of all pelagic spec.	$B_{pelagic}$ >75% B_{Σ} or $B_{pelagic}$ <20% B_{Σ}	$B_{pelagic}$ >85% B_{Σ} or $B_{pelagic}$ <10% B_{Σ}
B_{TL4+}	B of all spec. at trophic level 4 and above	B_{TL4+} >25% B_{TL3}	B_{TL4+} >50% B_{TL3}
B_{pisc}	B of all piscivores	N/A	B_{pisc} >B_{benth} + B_{plank}
L_{Σ}	Landings of target spec.	L_{Σ} >5% PP $\overline{L/S}_{max}$	L_{Σ} >10% PP
$\overline{L/S}$	Mean number of interactions per spec.	10% below	N/A
B_{remov}	Fishery removals of all spec. (landings, bycatch, discards, etc.)	N/A	B_{remov} >$B_{\Sigma Cons}$
S	Species richness (number of spec.)	S <S_{min}, for 3 yrs	S <S_{min}, for 5 yrs
C	Number of cycles	30% below C_{max}	N/A
N_{scav}	Abundance of scavengers	100% above $N_{scav\text{-}med}$	200% above $N_{scav\text{-}med}$
V_{jelly}	Volume of gelatinous zooplankton	100% above $V_{jelly\text{-}med}$	200% above $V_{jelly\text{-}med}$
A_{coral}	Area of live, hard coral	30% below A_{max}	50% below A_{max}

Assessing fishing impacts on fish communities without reference points

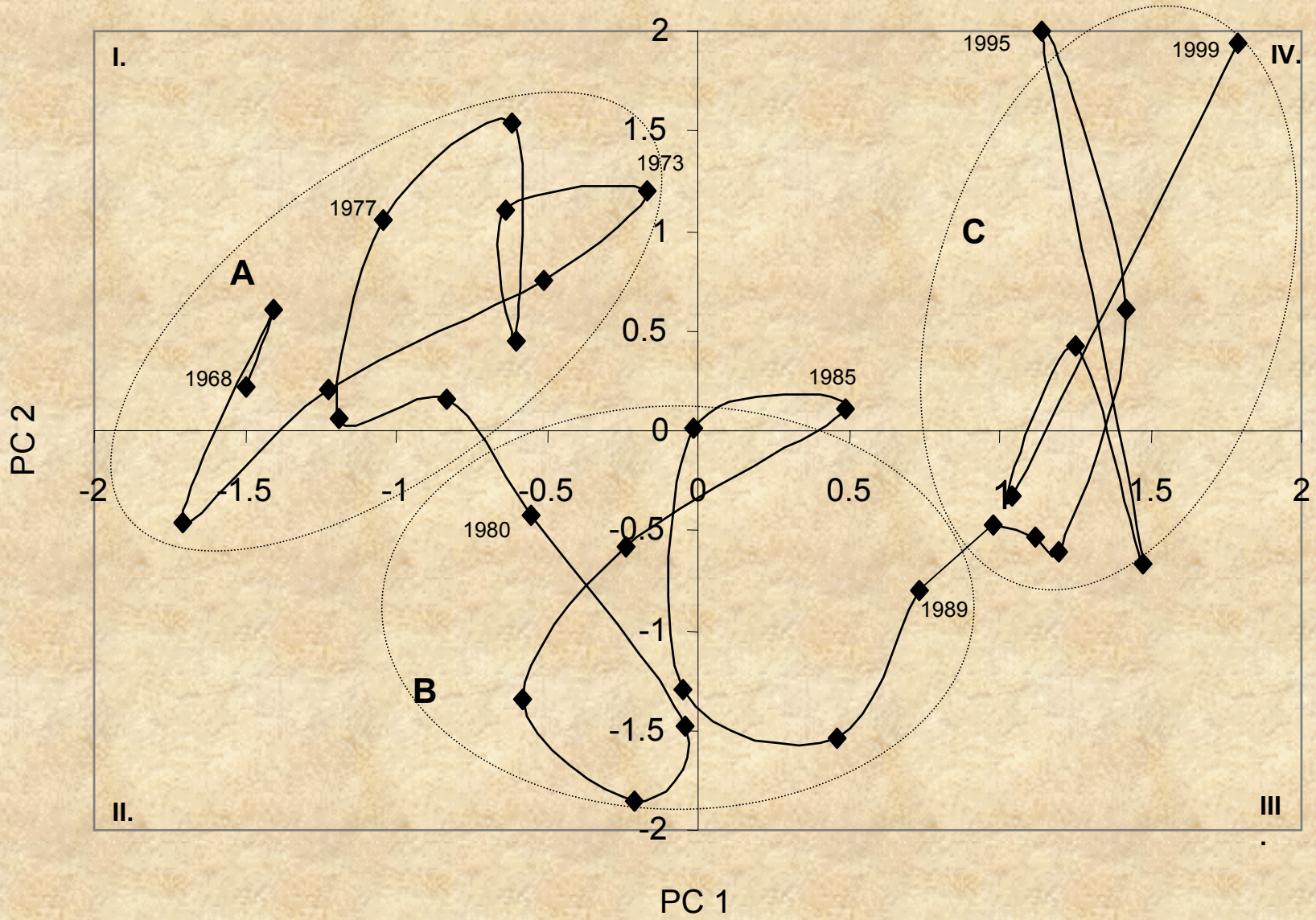
- Initial state assessment:
  - Were we happy where we started?
- Survey-based indicators
  - target / non target populations
  - community-level indicators
- Reference directions: tests for trends
  - fishing known to increase / decrease the indicator
  - *ie*: is the situation improving / worsening?

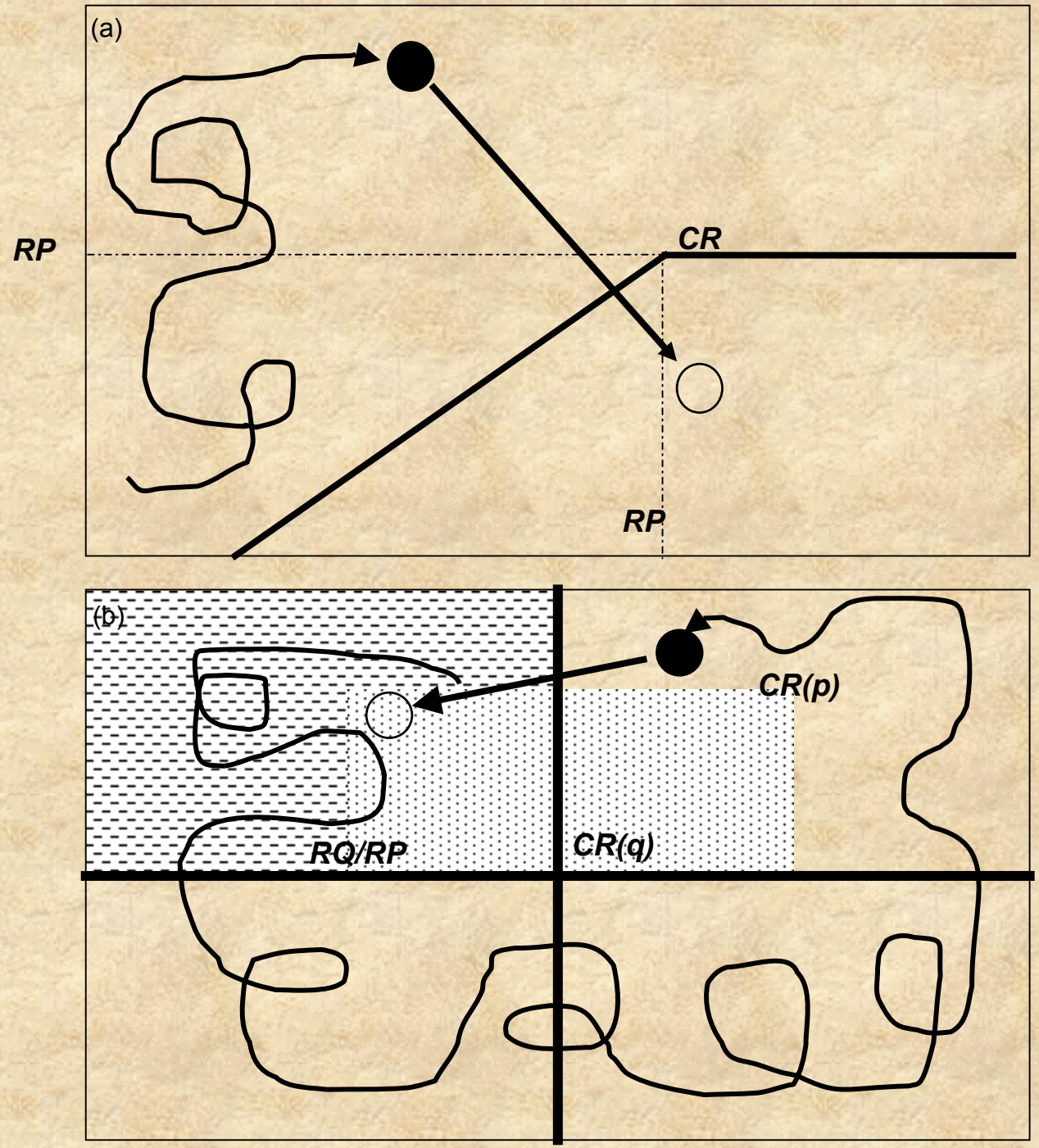
Reference Surfaces & AMOEBAS





Ordination & Reference Directions




(a)
RP
CR
RP
(b)
CR(p)
RQ/RP
CR(q)

Using Ecosystem Indicators: Prediction

KEY CONSIDERATIONS

1. MODELS that incorporate biological, human-induces and abiotic processes of interest

2. MANAGEMENT ALTERNATIVES to evaluate
   - Annual management measure setting
   - Management strategy evaluation of policies

3. SCENARIOS of future environmental state

Moving Beyond Status and Trends to Prediction and Forecasts

- Prediction of possible future trends under various management strategies: Requires Synthetic MODELS
- Provide guidance on possible aggregate effects of fishing and climate that are not captured under single species assessments

What do we need?

- Further Identification and Vetting of key ecosystem Indicators
- Establish Indicators as a function of F relative to other potential perturbations (yet remember, F is not the entire story of EAF)
- Novel ways to package & combine the multi-attribute, multivariate information
- Commitment to data sources
- Commitment to modeling resources and development
- More formalized decision analysis, MSE, DSS, and similar operations research to better use Translated Indicators
- And……